Design and Fabrication of Millimeter-wave Integrated Circuits Using Hexagonal Nanoferrite Materials

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Introduction

In this work, we present the design, simulation, fabrication and testing results of a self-bias microstrip line Barium hexagonal nanoferrite (BaM) circulator on silicon wafer. This planar Y-junction circulator is 2mm by 2mm by 0.5mm in size, which is capable of future integration with the top three layers of 180nm CMOS technology. Ferrite thin film is deposited and patterned employing composite spin-casting method. Typical characterization techniques are employed together with free-space quasi-optical spectrometry to study complex permittivity and permeability of deposited film up to 120GHz. S parameters of fabricated circulators are probe tested up to 67GHz. We observed over 15dB non-reciprocal phenomenon at 55GHz.

Ferrite Characterization

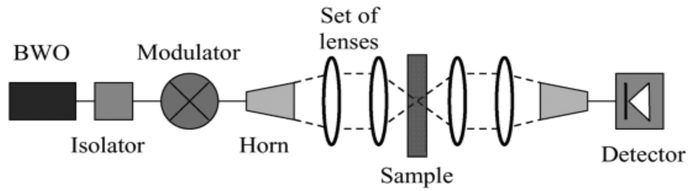


Figure 1: System schematic of quasi-optic spectrometer

➢ Quasi-optic Spectrometer (30-120 GHz)

Free space quasi-optic spectroscopy, a powerful non-destructive measurement technique in microwave and millimeter wave frequency range. Source of this quasi-optic spectrometer in Tufts High Frequency Material Measurement and Information Center is three high vacuum, high power backward wave oscillators (BWO) tunable in Q, V and W bands respectively. These three bands cover frequency range from 30 to 120 GHz.

Formula	BaFe12O19
Density (g/cm^3)	0.59
Diameter (nm)	~60
ε'	1.88
ε''	0.01
Loss tangent	0.0053
Anisotropic H_A (kOe)	16.5
Saturation $4\pi M_s$ (kG)	0.07
Resonant Frequency (GHz)	46.3

Table 1: Ferrite Composite Properties

➢ Ferrite Composite Preparation

The composite is prepared by mixing BaM nano-sized ferrite and AZ9260 polymer using a vortex mixer. The mass ratio of powder to polymer is 1:1 so that it contains large ratio of ferrite while maintain reasonable viscosity that can produce thin film after baking. We spin coated the composite onto aforementioned patterned wafer at a spin speed of 6000rpm then immediately moved it on a hope plate at 120°C and baked it under external magnetic field for 5 mins. The direction of magnetic field is perpendicular to the plane

Ferrite Characterization (cont.)

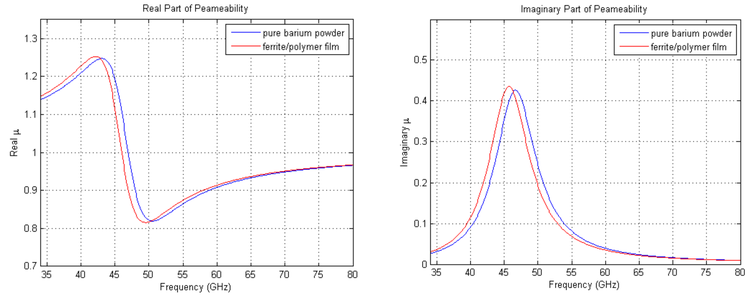


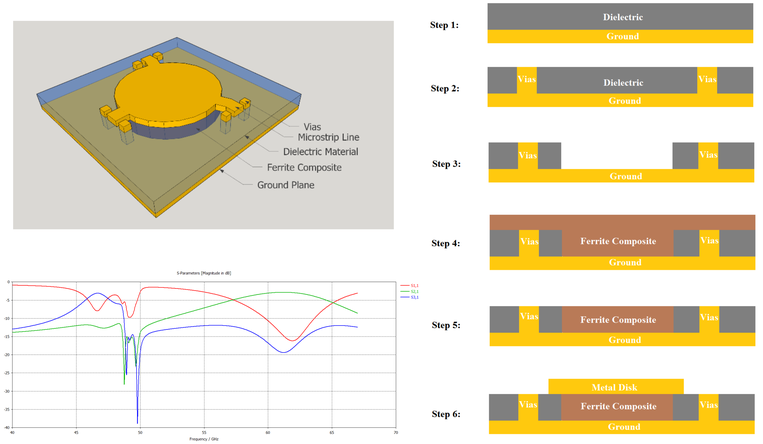
Figure 2: Real and imaginary part of permeability

Circulator Design and Fabrication

Out of numerous circulator types, we select three port Y-junction shape for the reason that it's an easier design with existing fabrication facilities. It's a three layer donut-like structure that have a metal circular disk with radius of R as a resonator operating at the desired frequency. Ferrite material fills the space between circulator disk and ground plane, shaped into a ferrite disk by the surrounding dielectric layer

From simulation results we can determine the performance as: Operation frequency: 62GHz; Insertion loss: -2.5dB; Isolation: 15dB.

Results are also cross-validated by employing another full wave EM simulation tool: HFSS. Similar simulation results are obtain except anisotropic phenomenon observed at slightly higher frequency comparting to results from CST.

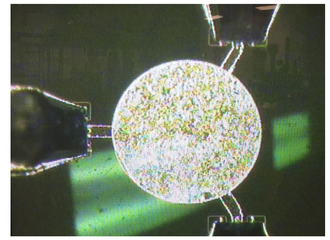


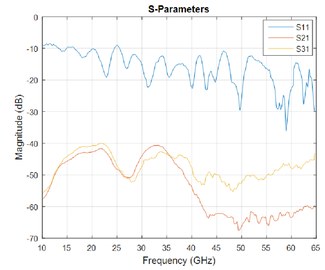
Top left: 3D model of out circulator; Bottom left: Simulation Results

Right: Step-by-step fabrication recipe

Measurement and Discussion

After fabrication, the three port device is measured by employing Agilent PNA N5227A network analyzer on a rotatable probe station. Measurement was implemented in the frequency range from 40 GHz to 67 GHz. At 55GHz the circulator exhibit 15dB non-reciprocal performance. Since three ports of circulator are identical and equivalent, it's justified to claim that S13= S32 =S21. In this case 15dB can also be regarded as isolation.





We believe there are following factors behind deviation of measurement from simulation results: a) Characteristic impedance of ports are around 5Ω. Impedance mismatch induces large portion of reflection at each ports; b) Quality of microstrip line and top metal disk is another source of loss in measured results. c) Most importantly the homogeneity of ferrite film is the critical factor that determine main magnetic and dielectric loss within device. Any pore or dent will become source of loss and kill the device. This could be improved by employing a new ferrite deposition method that can produce thin film with out-of-plane strong anisotropy and reasonable homogeneity.

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